Fatal Rollover Crashes in the Navajo Area.

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The Navajo Nation is the largest tribe of American Indians in both enrolled membership and reservation size. Injuries are the leading cause of death among the Navajo and are second only to pregnancy as a cause for hospitalization. The average unintentional injury death rate between 1982 to 1984 was 134 per 100,000 populations, almost twice the 1980 national rate of 71 per 100,000 population. Motor vehicle crashes were 60% of all unintentional injury deaths. The motor vehicle death rate of 88.3 per 100,000 was 3.5 times the national rate (25 per 100,000). The purpose of this study was to identify roadway and roadside characteristics where fatal rollover crashes occurred and to recommend environmental modifications and legislative actions to reduce rollovers.

Background

Rollover crashes have over twice the death rate of non-rollovers. This is partly due to the large proportion of occupants ejected from their vehicles in rollover crashes. Ejection is associated with a 25-fold increase in the risk of death. Federal Accident Reporting System (FARS) data for 1981-1985 indicates that in some rural states rollovers accounted for 24-41% of all crashes involving fatalities. There were 303 fatal rollovers in the Navajo Area between 1982 to 1985, 24% of all fatal crashes. This is comparable to national figures for rural states.

Fatal rollover crashes were more common in rural counties than urban. Possible reasons are inadequate emergency medical care, poor road conditions and design, excessive speeds, vehicle preference (pick-up trucks and utility vehicles), and a lower rate of seat belt use in rural states. The use of pick-ups and utility vehicles was higher in rural states, and these vehicles had a higher fatal rollover crash rate than sedans.

In 1975, May and Katz conducted a study of motor vehicle crashes on the Navajo Reservation. Based on interpretations of police-officer crash reports, the authors stated that single-vehicle crashes reflect mental and emotional instability. The authors concluded that single-vehicle crashes were "manifestations of social deviance and equivocal self-destruction in that they are related to driver characteristics and not to environmental factors such as weather, road conditions, etc". These conclusions were based on the high percentage of alcohol involvement in single-vehicle crashes, the relative young age of drivers, and the high percentage of drivers with no or invalid drivers' licenses. There was no detailed examination of where the crashes occurred or if there was "clustering" at specific locations. Driver characteristics or behavioral factors are undoubtedly important in single-vehicle crashes. However, if single-vehicle crashes are primarily manifestations of social deviance and self-destruction, one could expect these crashes to occur as random events along a given road. In fact, single-vehicle crashes are associated with specific locations having distinctive geometric characteristics.

Methods

This study was designed to compare roadway and roadside characteristics at fatal rollover crash sites with characteristics at a comparison or case control site one mile away. The field study procedures were similar to those used in previous studies of single-vehicle crashes. Differences between the crash and comparison sites can be used to identify locations where rollover crash fatalities are more likely to occur since exposure to the crash and comparison sites were usually equal.

The sites studied were the locations of fatal single-vehicle rollover crashes in the Navajo Area for the period of January 1, 1982 to December 31, 1985. Areas excluded from the study included that portion of the Navajo Reservation in the State of Utah and the Canoncito, Ramah and Alamo portions of the Reservation. These areas are a very small proportion of the Navajo Area and were excluded because of time limitations.

A total of 73 fatal rollover crashes occurred in the study area from 1982 to 1985. Of the 73 crashes, 45 were studied. This represents approximately 62% of all the fatal rollover crashes in the Navajo Area. Excluded from the study were 28 crash sites. These included 11 crashes where the site had been significantly altered by road construction and 6 crashes where no police report could be located. Also excluded were 8 crashes that involved another vehicle, 2 crashes that occurred on temporary dirt roads and one crash where the road had washed out making access to the crash site impossible. Studied were 23 crash and comparison sites on two-lane paved roads, 7 on Interstate Highway 40 (four-lane), and 15 on dirt roads. The crash sites were identified from Arizona, New Mexico, and Navajo Nation police reports. These reports were generally accurate as to crash locations and crash measurements. At the few sites where there was doubt concerning the exact location of the crash site, local people were interviewed or the investigating officer was contacted.

Engineering surveys were made by 3-person teams at the crash and comparison sites. The surveys were confined to a 0.2 mile section at each of the sites. In previous studies of fatal single-vehicle crashes in Georgia and New Mexico, the reference points for the crash sites were the locations where the vehicle came to rest. For this study, the reference point was where the investigating officers' report identified that the driver of the vehicle first had difficulty in controlling the vehicle. The reason for selecting this as the reference point was to survey the roadway where the drivers first lost control of the vehicle and not necessarily where the vehicle came to rest. In most cases the point of initial loss of control was identified on the police report by skids, scuff marks or vehicle tracks leaving the road.

The investigating officer utilized a fixed object as a permanent point and measured all longitudinal crash distances from this point. This permanent point was usually a pole, culvert or other permanent landmark. All crash site reference points were taken from this point. In some cases, crash debris also helped identify the site. A point 1 mile upstream (i.e. the direction from which the vehicle traveled) from the crash site was designated as the comparison or case control site. This point was selected as the comparison site because the vehicle was likely to have passed this site just minutes before reaching the crash site making exposure to both sites equal. The *condition of* the vehicle, driver, weather, lighting, etc. was assumed to have been the same for both sites because each site was passed within minutes of each other. When locating the comparison sites, choices at "T" or "Y" intersections were made randomly by the flip of a coin. This procedure was needed at 4 of the 45 comparison sites (9%).

Measurements were made of horizontal curvature, grade (road slope), lateral cross slopes (i.e. the slope of the road from the center line to the shoulder), shoulder slope, embankment slope, embankment height, bank slope, and road, lane and shoulder width. Lateral cross slope is termed “superelevation” on curved sections of a road and “crown” on straight sections. In this paper, lateral cross slope is referred to as superelevation.. All measurements were made at the reference point and at 100 foot intervals for 500 feet both upstream and downstream from the reference point at the crash and comparison sites.

A 100-foot cloth tape was used for measuring distances and curvature. Horizontal curvature measurements were made using a middle ordinate method. The curve measurements were usually taken on the edge of the roadway and the middle ordinates were converted to degrees of curvature at the centerline of the roadway. Superelevation and grade were measured at the centerline of the roadway lane used by the driver in approaching the crash location. These measurements and all slope measurements were made using a 3 foot carpenters level and a 10 foot metal tape. Unless otherwise noted, all statistical comparisons were by the T-test with $p <$ or $= 0.05$.

Results

Curvature: The predominant statistically significant difference between crash and comparison sites was road curvature, when the curvature was greater than 6 degrees ($p<0.001$). Twice as many of the crash sites (39%) as comparison sites (19%) had a maximum curvature of greater than 6 degrees. For those crash sites with a maximum curvature greater than 6 degrees, the greatest curvature occurred in the area between 500 to *300* feet upstream from the reference point and at the reference point.

To analyze the direction of the roadway curvature, left-turning curves were designated as positive curves (degrees of curvature were given + values) and right turning curves as negative curves. The average maximum curvature at the crash sites was +2.5 degrees. At the comparison sites the average maximum curvature was + 0*.53* degrees. Although both the crash and comparison average maximum curvatures indicate curves to the left, only the average maximum curvature for the crash sites was significantly different from zero.

Approximately 38% of the crash sites involved left turning curves. Of these, half involved left-turning curves greater than 6 degrees. For comparison sites, about 31% involved left-turning curves, but only *9%* involved left-turning curves greater than 6 degrees. There was a strong tendency for vehicles to leave the road on left-turning curves and on the outside or right side of the curves.

Superelevation: There were no significant differences in average superelevation at crash and comparison sites.

Grade: The mean grade at the crash site locations tended to be more negative or downgrade than at the comparison site locations. The mean grade at the crash sites was a minus 1.2% compared to minus 0.51% for the comparison sites. Analysis of variance indicates that the average differences in grade between the crash and comparison sites would not have commonly occurred as a result of random fluctuations in sampling ($p<0.005$).

Extreme downgrades of minus 4% or less were more common at crash sites than at comparison sites. Approximately 42% of the crash sites, compared to 31% of the comparison sites, had a minimum grade of minus 4% or steeper. An opposite distribution was true for relatively flat grades (minimum grade of a minus 1 to plus 1%). 43% of the comparison sites had a relatively flat grade versus only 25% of the crash sites.

An extreme downgrade alone was not substantially more characteristic of crash sites over comparison sites than were moderate downgrades. We investigated the minimum grade in the area 500 feet upstream from the crash and comparison sites reference points. A minimum grade of minus 3% or less was more frequent at approaches to crash sites while greater than minus 3% was more frequent at comparison sites ($p<0.05$).

The crash sites had a higher frequency of a combination of curvature and downgrade than did the comparison sites. 17% of the crash sites exhibited severe curves (>60) with a downgrade of less than minus 3%. Only 6% of the comparison sites exhibited the same features. The most hazardous combination of curvature and grade for fatal rollover crashes was a left-turning curvature of greater than 6 decrees on a downgrade of minus 3% or less.

<u>Roadside Measurements</u>: 61% of the fatal crash sites, and only 18% of the comparison sites, had a mean embankment slope of 20% or greater. The differences in distribution of embankment slope between the crash and comparison sites could probably not have occurred from chance fluctuation in sampling ($p<0.006$.). The average shoulder slopes at the comparison site locations were all higher than at the crash site locations . An analysis of variance of the shoulder slopes indicated that the differences would probably not have occurred as a result of random fluctuations in sampling. There were no significant differences between the crash and comparison sites for average bank slopes, shoulder width, lane width or road width.

<u>General Crash Data</u>: The investigating officers' reports were used to determine general information on fatal rollover crashes. Based on officers' sketches and measurements at the crash site, longitudinal distances (i.e. the distance from the point where the driver first lost control to where the vehicle came to rest) for all crashes ranged from 108 feet to 962 feet. The average longitudinal distance was 328 feet. The longitudinal distances for crashes on dirt roads were generally shorter (range from 108 feet to 387 feet, mean = 236 feet) than for crashes on paved roads, which ranged from 118 feet to 962 feet with a mean distance of 321 feet. The longitudinal distances traveled were most likely the result of the vehicle speed at the time of the crash.

The lateral distances (distance vehicle traveled off the roadway) for all crashes, ranged from 0 to 140 feet with an average of 38 feet. The lateral distances for crashes on dirt roads were shorter than for paved roads. Dirt road lateral distances ranged from 0 to 38 feet with a mean of 18 feet. Paved road lateral distances ranged from 0 to 140 feet with a mean of 40.2 feet. These distances are also most likely the result of the vehicle speed at the time of the crash.

In 67% of the crashes there was no seat belt use by anyone in the vehicle. Seat belts were used in 2% of the crashes, and in 31% there was no indication as to seat belt use. The 2% seat belt use involved one fatal crash in which the passengers wore seat belts and were not severely injured; the unbelted driver was fatally injured. In the 45 fatal crashes, 80% of the victims were fully ejected from the vehicle, 9% partially ejected, 2% were not ejected. In 9% ejection status was unknown.

Pickups were the principle vehicle type involved in the fatal rollover crashes accounting for 54.5%. Sedans accounted for 27.3% and utility vehicles accounted for 13.6% of the crashes. Data on vehicle registration in the study area was not available to determine exposure rates for the different types of vehicles. The most frequently reported contributing factor in the investigating officers' reports was excessive speed, noted in 76% of the fatal rollover crashes. In only 4% was speed not a factor; in 20%, the contribution of speed to the crash was not indicated.

89% of the drivers were males, 9% were females, and in 2% of the crashes the sex of the driver was not listed. 70% of the drivers were between 16 to 29 years of age. The majority of the drivers (51%) had a valid drivers' license and 38% did not have a valid license. The investigating officers listed alcohol involvement in 56% of the crashes and no involvement in 24%. Alcohol involvement was unknown in 20%. In the great majority of cases, evidence of alcohol involvement was subjective. The majority of the fatal rollover crashes occurred during the day (67%), on dry roads (80%), and during clear weather (82%). Fatal rollovers occurred most frequently in May and October and least frequently in February, August, and December. The most frequent time of day for rollover was between 4 pm - 5:00 pm. Almost 50% of the fatal rollovers were between 2 pm and 10 pm.

Discussion

Two events occur in a rollover crash. In the first, the vehicle generally leaves the roadway, and, second, the vehicle overturns. Roadway geometry is a significant contributing factor in vehicles leaving the roadway. Characteristics of the roadside contribute to vehicles overturning. In the Navajo area, a motor vehicle is more likely to leave the roadway at a site with a horizontal curvature of over 6 degrees, especially a left-turning curvature, and a downhill grade of minus 3% or less. Other studies of single-vehicle fixed object and rollover crashes have reported similar results, although the maximum curvature and minimum grades reported varied by 1 degree or 1%.

The selection of the site reference point could partially explain the differences between the horizontal curvature and grade results in this study versus previous studies. In previous studies, the reference point was the location where the vehicle came to rest. In this study, the reference point was the location where the driver of the vehicle first had difficulty in controlling the vehicle and not where the vehicle came to rest. This placed our reference points about 300 feet upstream from where they would have been in the other studies. This difference in reference points would produce slightly different curvature and grade results. In earlier, the area upstream from the reference point had a relatively steeper grade and a higher degree of curvature than areas downstream from the reference point.

Another factor in vehicles leaving the roadway is superelevation or "banking". The superelevation results were somewhat unexpected. A relatively higher superelevation preceding the crash sites was expected because the area preceding the crash sites tended to have a higher degree of curvature than the comparison sites, and because superelevation is generally increased in areas of higher curvature.

Superelevation of curves on area roads may be inadequate. When a vehicle enters a curve, forces tend to push the vehicle to the outside, forces which increase as the vehicle speed increases. Inadequate superelevation increases the risk of a driver losing control of a vehicle and leaving the road on the outside of a left-turning curve. This was the most frequent path taken by vehicles leaving the roadway in this study. The fate of the vehicle after leaving the roadway depends, to some extent, on roadside characteristics. The steepness of the embankment slope or front slope was associated with fatal rollover crashes. The average embankment slope at the crash sites was most frequently 20% or greater, versus 15% or less at the comparison sites. Embankment slopes of 20% are considered traversable. This study indicates, however, that vehicles leaving the roadway have difficulty traversing slopes of 20% or greater.

If a location has an embankment slope of 33% or greater, or an embankment height of 4 feet or greater, a guard-rail should be installed (in these circumstances, it is believed that impact with a guardrail would be more hazardous to the vehicle occupants than the consequences of leaving the road). 82% of the crash sites did not meet the embankment slope standard for the installation of guardrails; 66% did not meet the embankment height standard. In a New Mexico rollover study, the average embankment slope was 25%; more than 50% of the embankments had heights of less than 4 feet. The development of energy-absorbing guardrails further suggests the need to reevaluate the existing guardrail standards. Most of the guardrails noted during this study were installed only on the most severe part of a curve and did not extend beyond the curve. Drivers tended to lose control of their vehicle as they came out of a severe curve. Extending the guardrails beyond the curve to include the area where the drivers lose control may reduce rollover crashes.

Another characteristic of the roadside that may contribute to rollover crashes is the change in lateral slope at the hinge point (the point where the shoulder meets the embankment). The average change in lateral slope at the crash site was approximately 45%, versus 15.6% at the comparison sites. The sudden change in lateral slope may contribute to vehicles rolling over, or at least to the driver losing further control of the vehicle.

The design features of the roadway partially explain the differences in rollover crash rates at different sites along a road. Downhill grade combined with excessive curvature, especially left-turning curvature, and inadequate superelevation seem to increase the demands on the driver to control the vehicle. The increased demands sometimes result in the vehicle leaving the roadway. Once the vehicle has left the roadway, its fate is primarily dependent on roadside characteristics.

Recommendations

There are no national standards for prioritizing road improvements to reduce rollover crashes. For existing roads and designs for new roads, where possible, horizontal curvatures of greater than 6 degrees and downhill grades of approximately 3% or greater should be eliminated . Roads should also be designed and improved to include adequate superelevation on curves. These changes should reduce the risk of a vehicle leaving the road. Reducing embankment slopes to 20% or less, and reducing severe changes in lateral slopes at the hinge point, should reduce the risk of overturning. For sites where changing the geometry of the road is not possible because of cost or other factors, properly installed, energy-absorbing guardrails that extend beyond the curve should be considered. The organizations that establish standards for guardrail installation should reevaluate the existing guardrail standards.

Installation of reflectors on the centerline and edge of the roadway will better define curves. In one state where centerline reflectors were installed at sites with a high degree of curvature and downhill grade, there was a 20% reduction in these crashes at night. To reduce vehicles leaving the road during daylight hours and in areas where reflectors are not feasible, it may be practical to erect roadside markers to further define the curve.

In several of the police officers' reports, the driver took no evasive action to prevent leaving the roadway. The drivers were apparently not aware they were leaving the roadway. Altering the texture of the roadway surface at the shoulder (by cuts or grooves in the road) may alert drivers that the vehicle is leaving the roadway. The road noise from the tires would change in pitch or tone over the textured surface on the shoulder, thus alerting the driver.

Drivers were exceeding the posted speed limit in the majority of the rollover crashes. On dirt roads, where there usually was no posted speed limit, drivers were driving too fast for the conditions. The regulatory authorities for the Navajo Nation and the states should establish and post speed limits for major dirt roads. In addition, posting reduced speed limits at hazardous sites on dirt and paved roads may further reduce rollover crashes.

The Navajo Nation and the State of Arizona do not have seat belt laws. New Mexico's seat belt law exempts the occupants of certain types of vehicles (pick-up trucks, utility vehicles, vans.). The vast majority of fatalities in this study were ejected from their vehicle during the rollover. The Navajo Nation and the state of Arizona should adopt comprehensive seat belt laws, and, for the Navajo Nation, child restraint laws. These laws should include all vehicles. The state of New Mexico should amend their existing seat belt law to include all vehicles.

The results of this study can help identify hazardous locations for rollover single-vehicle crashes. They can be used as guidelines for establishing priorities for roadway and for roadside improvements to reduce rollover crashes. Further study is needed on the possible effects the recommended alterations at sites with a high degree of curvature and downhill grade may have on reducing rollover crashes.